



Three-Dimensional Volume Rendering Anatomy of the Carotid Canal

Karotid Kanalin Üç Boyutlu Hacim Betimleme Anatomisi

Carotid Canal

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Özet

İnternal karotid arter, kafatasına temporal kemiğin petröz parçasından karotid kanal yoluyla girmektedir. Bu çalışmaya intrakranial anevrizmaların varlığının tespiti için bilgisayarlı tomografik anjiyografileri değerlendirilen hastalar dahil edildi. Anjiyografik veriler DICOM formatında kaydedilip görüntü analiz yazılımları kullanılarak üç boyutlu nörovasküler görüntü formatına dönüştürüldü. 54 hastaya ait veriler (27 erkek, 27 bayan) karotid kanal açısından değerlendirildi. Erkeklerde karotid kanal giriş boyutları anteriordan posteriora doğru sağda $0,44 \pm 0,085$ (Ortalama±Standart ortalama hata) cm olarak bulunurken sol tarafta $0,48 \pm 0,1$ cm olarak bulundu. Bayanlarda bu değerler sağ tarafta $0,45 \pm 0,11$ cm, sol tarafta $0,42 \pm 0,1$ cm olarak tespit edildi. Bununla birlikte medial-lateral boyutlar erkeklerde sağ tarafta $0,58 \pm 0,11$ cm, sol tarafta $0,61 \pm 0,13$ cm olarak tespit edildi. Bayanlarda bu değerler sağ tarafta $0,53 \pm 0,093$ cm, sol tarafta $0,51 \pm 0,12$ cm olarak bulundu. Bu çalışmada karotid kanalın giriş ve çıkış foramenlerine ait ölçüler tanımlanmıştır.

Anahtar Kelimeler

Karotid Kanal; Karotid Foramen; Hacim Betimleme Tekniği; Üç Boyutlu Görüntüler; Bilgisayarlı Tomografi

Abstract

The internal carotid artery enters the skull via the carotid canal in the petrous portion of the temporal bone. To evaluate the presence or absence of intracranial aneurysms, the patients included in this study were evaluated with computerized tomographic angiography. Imaging data were stored in digital imaging and communications in medicine (DICOM) format and subsequently converted by imaging software into three-dimensional volume rendered neurovascular images. Three-dimensional volume rendered neurovascular images of the 54 patients (27 male and 27 female) were evaluated in the analysis of the carotid canal. In the males, the dimension of the carotid canal entrance from anterior to posterior direction was estimated as 0.44 ± 0.085 (Mean±SEM) centimeters on the right side and 0.48 ± 0.1 centimeters on the left side. In females, the values were estimated as 0.45 ± 0.11 centimeters on the right side and 0.42 ± 0.1 centimeters on the left side. In the males, the medial-lateral dimensions were estimated as 0.58 ± 0.11 centimeters on the right side and 0.61 ± 0.13 centimeters on the left side. In the female, the medial-lateral dimensions were estimated as 0.53 ± 0.093 centimeters on the right side and 0.51 ± 0.12 centimeters on the left side. The present study describes the entrance and exit foramina of the carotid canal and the dimensions of certain anatomical structures of interest.

Keywords

The Carotid Canal; Carotid Foramen; Volume Rendering Technique; Three-Dimensional Images; Computerized Tomography

DOI: 10.4328/JCAM.4679

Received: 01.06.2016 Accepted: 12.06.2016 Printed: 01.11.2016 J Clin Anal Med 2016;7(6): 835-9

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Introduction

The term carotid derives from the Greek *karos* or *karoun* meaning a deep sleep or to stupefy. This term is related to the physiologic function of the internal carotid artery, which carries oxygen and nutrients to the brain tissue. If this supply is interrupted the individual falls into unconsciousness. The term canal is derived from the Latin *canalis* meaning a tube or channel. The internal carotid artery enters the skull via the carotid canal in the petrous portion of the temporal bone. At the level of the superior border of the thyroid cartilage, the common carotid artery divides into the internal and external carotid arteries. The internal carotid artery ascends superiorly through to the carotid canal in nearly the same line as the common carotid artery. The internal carotid artery lies in the retro-mandibular fossa deep in the parotid gland and just ventral to the transverse processes to the atlas, axis, and third cervical vertebrae. In 1938, Fischer first classified the segments of the internal carotid artery based on angiographic evaluation [5]. Some other published classification systems have proposed different classifications, numbering the segments of the internal carotid artery in the direction of blood flow [1,6,7,9,11,18]. At the entrance level to the carotid canal, the internal carotid artery is located in front of the jugular vein and lateral to a lamina of bone called the vaginal process, which is part of the tympanic bone.

In the present study, the shape and dimensions of the carotid foramen, and the distance of the foramen from certain important anatomical structures were evaluated based on the three-dimensional volume rendered neurovascular images. This, with a review of the literature, is used to describe the micro-vascular anatomy of the carotid canal.

Material and Method

Additional radiological examinations were performed and drugs were provided to the patients in this study, as necessary and appropriate. The patient population for this study arrived at our neurosurgery department because of subarachnoid hemorrhage. It was decided to perform a 3D-CTA for cerebral aneurysm evaluation. The raw data of the 3D-CTA were transferred and recorded in a computational software database. Some of these raw data were used for software analysis of the three-dimensional anatomy of the carotid canal. Any additional procedures needed by any of the patients were performed.

To evaluate the presence or absence of intracranial aneurysms, the patients included in this study were evaluated with computerized tomographic angiography. When an aneurysm was detected, the optimal appropriate management, either surgical clipping or endovascular coiling, was offered to the patients and their families.

The images analyzed in this study were captured using the Aquilion ONE multidetector row computerized tomography scanner (Toshiba, Medical Systems, Tokyo, Japan). Detailed instruction was given to all patients to lie on the table with mouth and eyes closed. An external fixation device was used when necessary to stabilize the patient's head. After obtaining a frontal and lateral scanogram, a conventional unenhanced computerized tomography was performed, if necessary, depending on the clinical purpose (120 kV, 200 mAs).

Computerized tomographic angiography images were acquired

following intravenous timed injection of a contrast agent (Visipaque [Iodixanol] 270 mg/100 ml, OPAKIM) using an auto-triggered mechanical injector. The injection rate was 4 ml/s to a total injection volume of 40 ml of contrast agent followed by injection of 20 ml of contrast agent at 3 ml/s. Transverse scans were acquired in the helical mode with radiation parameters 120 kV and 300 mA, matrix size 512 x 512, field of view (FOV) 28-32 cm, slice thickness 1 mm, pitch 1.0, and isotropic voxel size 0.5 mm. The acquisition time was 11-16 s.

Imaging data were stored in digital imaging and communications in medicine format and subsequently analyzed with OsiriX imaging software (OsiriX Foundation, Geneva, Switzerland). Three-dimensional reconstruction of the data was performed to permit viewing of the anatomical area of interest. Settings for the three-dimensional reconstruction algorithm are described below. The database window of the program was opened to find the patient's two-dimensional computerized tomographic angiography images sequence. The imaging cluster was unpacked to the front window. 3D Volume Rendering option was selected to create a three-dimensional volume rendered image after the opening of 2D/3D Reconstruction Tools from the dashboard. Following the automatic opening of the next window, the volume rendered image graphics processing unit (GPU) engine was selected to render the image at the best resolution. If it is necessary to remove the artifact from the head fixation device, the Sculpt function can be selected to remove the artifact from the working window. A mouse button function allows rotation of the image around a focal point, perpendicular to the anatomic area of interest. The button for the zoom function can also be selected for magnification of the image. Then, Window-Level section was selected to arrange the opacity of the image for maximal reconstruction of the vascular and/or bone structures. The Measurement button was selected in the estimation of diameter, width, and length of the structures as well as the measurement of the distance between two different points (Figure 1).

Results

To evaluate the presence or absence of intracranial aneurysms, the bilateral carotid canals of 54 patients (27 male and 27 female) included in this study were evaluated with computerized tomographic angiography. The mean age of the patients was 55.33 ± 9.4 . Three-dimensional volume rendered neurovascular images based on the computerized tomographic angiography were evaluated in analyzing the shape of the entrance, dimensions of the foramen, and distance from certain anatomical structures.

Three types of general geometrical shapes were identified: angular, circular, and ovoid. In males, the dimension of the carotid canal entrance from anterior to posterior direction was estimated as 0.44 ± 0.085 centimeters on the right side and 0.48 ± 0.1 centimeters on the left side. In females, the values were estimated as 0.45 ± 0.11 centimeters on the right side and 0.42 ± 0.1 centimeters on the left side. In males, the medial-lateral dimensions were estimated as 0.58 ± 0.11 centimeters on the right side and 0.61 ± 0.13 centimeters on the left side. In females, the medial-lateral dimensions were estimated as 0.53 ± 0.093 centimeters on the right side and 0.51 ± 0.12 centimeters on the left side (Table 1).

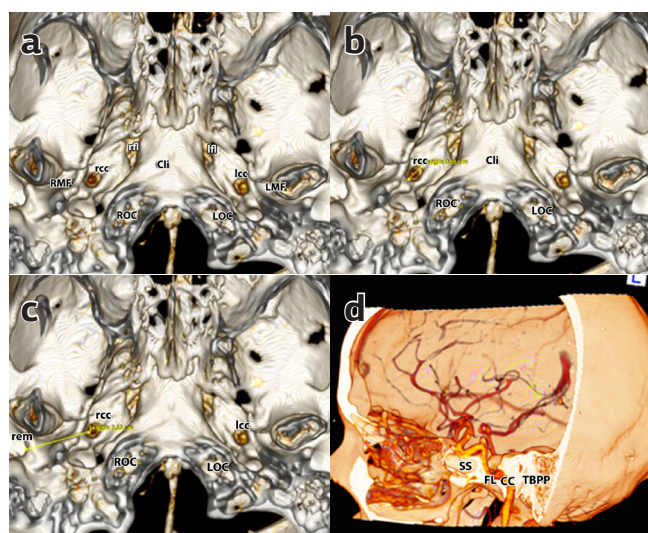


Figure 1. The three-dimensional volume rendered images of the skull base in the superior aspect (Cli:Clivus, rcc:right carotid canal, lcc:left carotid canal, rfl:right foramen lacerum, lfl:left foramen lacerum, Rmf:right mandibular fossa, Lmf:left mandibular fossa, ROC:right occipital condyle, LOC:left occipital condyle) (a) The using of measurement tool in the measurement of the right carotid canal. (rcc:right carotid canal, Cli:Clivus, ROC:right occipital condyle, LOC:left occipital condyle) (b) The estimation of the distances of the right carotid canal from the right external meatus. (rcc:right carotid canal, lcc:left carotid canal, rem:right external meatus, ROC: right occipital condyle, LOC:left occipital condyle) (c), The three-dimensional volume rendered images of the skull base in the lateral aspect. (CC:carotid canal, SS:Sphenoid sinus, TBPP:Temporal bone petrous part, FL:foramen lacerum) (d).

Table I. Dimensions of the carotid canal at the entrance point in males and females

	N	RIGHT		LEFT	
		Anterior-Posterior	Medial-Lateral	Anterior-Posterior	Medial-Lateral
Male	27	0.44±0.085	0.58±0.11	0.48±0.1	0.61±0.13
Female	27	0.45±0.11	0.53±0.093	0.42±0.1	0.51±0.12

In males, the distance from the external margin of the mandibular fossa was estimated as 3.11±0.26 centimeters on the right side and 3.06±0.35 centimeters on the left side. In females, the measurements were estimated as 3.13±0.63 centimeters on the right side and 2.78±0.81 centimeters on the left side. In males, the distance from the external meatus was estimated as 2.07±0.22 centimeters on the right side and 2.06±0.24 centimeters on the left side. In females, the values were estimated as 1.95±0.26 centimeters on the right side and 1.95±0.36 centimeters on the left side (Table 2).

In males, the distance from the tip of the mastoid process was estimated as 2.86±0.4 centimeters on the right side and 2.98±0.39 centimeters on the left side. In females, the values were estimated as 2.71±0.34 centimeters on the right side and 2.86±0.46 centimeters on the left side.

In males, the distance from the outer margin of the mastoid incisura was estimated as 3.79±0.61 centimeters on the right side and 3.95±0.47 centimeters on the left side. In females, the measurements were estimated as 3.5±0.33 centimeters on the right side and 3.78±0.38 centimeters on the left side. In males, the distance from the midline posterior margin of the occipital condyle was estimated as 2.31±0.24 centimeters on the right side and 2.34±0.42 centimeters on the left side. In females, the measure-

ments were estimated as 2.3±0.2 centimeters on the right side and 2.24±0.31 centimeters on the left side. In males, the distance from the midline anterior border of the foramen magnum was estimated as 4.89±0.44 centimeters on the right side and 4.86±0.48 centimeters on the left side. In females, the measurements were estimated as 4.76±0.35 centimeters on the right side and 4.72±0.27 centimeters on the left side (Table 3).

Discussion

The carotid canal is the curved bony channel located in the petrous temporal bone. The petrous portion of the internal carotid artery and carotid sympathetic nerve plexus passes through the carotid canal to reach the foramen lacerum. The canal starts on the inferior surface of the temporal bone at the external opening of the carotid canal. The inferior opening of the channel is also referred to as the carotid foramen. This circular or oval opening courses superiorly into the bone for about 0.5-1 centimeters before its antero-medial bending. The canal ends at the petrous apex. The canal's internal opening is near the foramen lacerum above, which the internal carotid artery passes on its way to the cavernous sinus.

The Latin term canal describes a tubular shape of passage with two openings. Like other canals, the carotid canal has two exits. The first opening is the entrance foramen of the internal carotid artery. This foramen faces the inferior external aspect of the cranial base. The second opening is located at the foramen lacerum. The internal carotid artery leaves from the carotid canal via this foramen. This foramen faces the foramen lacerum and may be referred to as the anterior carotid foramen. This foramen is anatomically located in front of the other foramen, which may be referred to as the inferior carotid foramen. The inferior carotid foramen is perpendicularly located at the cranial base. The anterior carotid foramen is vertically located at the base of the cranium facing the foramen lacerum. The anatomic location of the foramen lacerum is perpendicular. The carotid foramen has two portions inside the petrous portion of the temporal bone—a vertical part and a horizontal part. The vertical part follows the inferior carotid foramen. The vertical part turns sharply to the anterior direction until reaching the foramen lacerum via the anterior carotid foramen.

The three-dimensional anatomical course of the internal carotid artery and the carotid canal should be taken into account

Table II. Distance of the carotid canal from the mandibular fossa, external meatus, mastoid tip, mastoid incisura, occipital condyle, and foramen magnum on the right side in males and females.

	N	RIGHT SIDE					
		Mandibular Fossa	External Meatus	Mastoid Tip	Mastoid Incisura	Occipital Condyle	Foramen Magnum
Male	27	3.11±0.26	2.07±0.22	2.86±0.4	3.79±0.61	2.31±0.24	4.89±0.44
Female	27	3.13±0.63	1.95±0.26	2.71±0.34	3.5±0.33	2.3±0.2	4.76±0.35

Table III. Distance of the carotid canal from the mandibular fossa, external meatus, mastoid tip, mastoid incisura, occipital condyle, and foramen magnum on the left side of males and females.

	N	LEFT SIDE					
		Mandibular Fossa	External Meatus	Mastoid Tip	Mastoid Incisura	Occipital Condyle	Foramen Magnum
Male	27	3.06±0.35	2.06±0.24	2.98±0.39	3.95±0.47	2.34±0.42	4.86±0.48
Female	27	2.78±0.81	1.95±0.36	2.86±0.46	3.78±0.38	2.34±0.42	4.72±0.27

in those patients needing surgical intervention in the middle cranial base. Recently, Bouthillier et al. proposed a classification system that describes the entire internal carotid artery, uses a numerical scale in the direction of blood flow, and identifies the segments of the internal carotid artery according to the anatomy surrounding the internal carotid artery and the compartments through which it travels [1]. According to this classification, the internal carotid artery has seven segments: C1, cervical; C2, petrous; C3, lacerum; C4, cavernous; C5, clinoid; C6, ophthalmic; and C7, communicating. Ziyal et al. have suggested some modifications for the classification of the entire internal carotid artery [18]. According to their classification, the internal carotid artery can be divided into five segments: cervical, petrous, cavernous, clinoidal, and cisternal [18]. Rhoton classified the internal carotid artery into four parts: the C1, or cervical portion, extends from its junction with the common carotid artery to the external orifice of the carotid canal; the C2, or petrous portion, courses within the carotid canal and ends where the artery enters the cavernous sinus; the C3, or cavernous portion, courses within the cavernous sinus and ends where the artery passes through the dura mater forming the roof of the cavernous sinus; and the C4, or supraclinoid portion, begins where the artery enters the subarachnoid space and terminates at the bifurcation into the anterior and middle cerebral arteries [13].

The volume rendering technique may be used in the three-dimensional evaluation of certain anatomical structures such as the internal carotid artery. Volume rendering technique is a group of modalities for converting two-dimensional images into three-dimensional images [2,8,12]. The two-dimensional images acquired by computerized tomography and magnetic resonance imaging are used to create the volume rendered images [2,4,12]. Digital subtraction angiography is still the most sensitive diagnostic procedure in the evaluation of intracranial and extracranial vascular lesions such as aneurysms and arteriovenous malformations [3,8]. However, digital subtraction angiography is expensive, invasive, and brings some associated (1.5% to 2.0%) risk of significant morbidity and mortality [15]. Computerized tomographic angiography with its three-dimensional advantage is commonly used for intracranial aneurysm detection. In the published literature, the diagnostic sensitivity of computerized tomographic angiography was reported between the range of 70% and 96% depending on the size and location of the pathology [10,14,16,17]. Three-dimensional viewers provide modern rendering modes such as multiplanar reconstruction, surface rendering, volume rendering, and maximum intensity projection. In the present study, we used OsiriX software in the processing of DICOM images. This software may show the basal cerebral arteries and cervical segment of the internal carotid arteries together with the bone structure of the cranial base including the carotid canal.

In the male patients we studied, the dimension of the inferior carotid foramen (the entrance of the carotid canal) from anterior to posterior direction was estimated as 0.44 ± 0.085 centimeters on the right side and 0.48 ± 0.1 centimeters on the left side. The anterior-posterior diameter of the left side was 7.56% higher than the right side. In the same population, the left medial-lateral diameter of the inferior carotid canal was

3.58% higher than the left side. In females, the dimension of the inferior carotid foramen from anterior to posterior direction was estimated as 0.45 ± 0.085 centimeters on the right side and 0.42 ± 0.1 centimeters on the left side. The anterior-posterior diameter of the left side was 3.42% lower than the right side. In the same population, the left medial-lateral diameter of the inferior carotid canal was 3.92% lower than left side. The anterior-posterior dimensions for female and male individuals were nearly equal to the right side. On the left side, the anterior-posterior dimension of the males was 14.28% higher than in females. On the left side, the anterior-posterior dimension of the carotid canal in males was 14.28% higher than in females. The right medial-lateral dimension of the males was 9.43% higher than in females. The left medial-lateral dimension was 19.6% higher than in females.

In this study, six anatomical points were selected to estimate the distance of the inferior carotid foramen from some important surgical points: external midline margin of the mandibular fossa; external meatus; the tip of the mastoid process; the outer margin of the mastoid incisura; midline posterior margin of the occipital condyle; and midline anterior border of the foramen magnum. In male and female individuals, the distance from the external margin of the mandibular fossa was found to be nearly equal on the right side. On the left side, the distance for males was 12.58% higher than for females. In males, the distance of the inferior carotid foramen from the external meatus was estimated as 2.07 ± 0.22 centimeter on the right side; this value is 6.15% higher than in females. On the left side this value is nearly equal with the right side. The mastoid tip and mastoid incisura are also important anatomical landmarks. The distance of the inferior carotid foramen from the tip of the mastoid process was estimated as 2.86 ± 0.4 centimeters in males on the right side. The distances for females were 5.24% lower on the right side and 4.02% lower on the left side than for males. The differences of the distance of the mastoid incisura from the inferior carotid foramen were found as 7.65% and 4.3% higher in males on the right and left sides, respectively. The distance from the posterior midline point to the inferior carotid foramen was nearly equal in male and female individuals. The difference of the distance of the anterior midline point of the foramen magnum from the inferior carotid foramen was 2.88% higher in males on the right and left side.

In summary, in this study a three-dimensional volume rendering technique was used to evaluate the carotid canal. The study describes two openings of the canal. The first opening is the entrance of the canal in terms of the direction of the blood flow. This opening is named the inferior carotid canal because of its location behind the second opening, which is the opening window to the foramen lacerum. This foramen is named the anterior carotid foramen. Anterior-to-posterior and medial-to-lateral dimensions of the canal were estimated for male and female patients and compared. Also, distance from some important anatomical landmarks was evaluated. The results of this study show that the three-dimensional volume rendering technique can be used in the evaluation of cranial base structure including micro-vascular surgical anatomy. Further evaluation of biomechanics, flow dynamics, and interaction with perivascular neural cranial base structures is needed.

Competing interests

The authors declare that they have no competing interests.

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How to cite this article:

Kuruoğlu E, Onger ME, Çokluk C. Three-Dimensional Volume Rendering Anatomy of the Carotid Canal. *J Clin Anal Med* 2016;7(6): 835-9.